

WHAT IS CLAIMED IS:

[c1] A permanent magnet assembly for an imaging apparatus comprising a permanent magnet body having a first surface and a stepped second surface which is adapted to face an imaging volume of the imaging apparatus, wherein the stepped second surface contains at least four steps.

[c2] The assembly of claim 1, further comprising at least one layer of soft magnetic material attached to a substantially flat first surface of the permanent magnet body.

[c3] The assembly of claim 2, wherein the permanent magnet body comprises a permanent magnet RMB material, where R comprises at least one rare earth element and M comprises at least one transition metal.

[c4] The assembly of claim 3, wherein:
the permanent magnet RMB material comprises 13-19 atomic percent R, 4-20 atomic percent B and the balance M, where R comprises 50 atomic percent or greater Pr, 0.1-10 atomic percent of at least one of Ce, Y and La, and the balance Nd, and M comprises Fe; and
the at least one layer of a soft magnetic material comprises a laminate of Fe-Si, Fe-Al, Fe-Co, Fe-Ni, Fe-Al-Si, Fe-Co-V, Fe-Cr-Ni or amorphous Fe- or Co-base alloy layers.

[c5] The assembly of claim 2, wherein the permanent magnet body comprises:
a cylindrical base section having a major first surface attached to the at least one layer of a soft magnetic material and a major second surface having at least three steps, wherein the second surface of the base section is opposite to the first surface of the base section; and
a hollow ring section attached to an outer portion of second surface of the base section.

[c6] The assembly of claim 5, wherein:

the first and second surfaces of the base section and the first and second surfaces of the hollow ring section are arranged substantially perpendicular to a direction of a magnetic field of the magnet assembly;

the stepped second surface of the permanent magnet body comprises the second surface of the hollow ring section and a portion of the second surface of the base section that is not covered by the ring section;

the base section comprises at least two layers of permanent magnet blocks;
and

at least two of the steps in the second surface of the base section are machined into the second surface of the base section.

[c7] The assembly of claim 6, wherein the second surface of the ring section extends at least 0.05 meters above an outer step on the second surface of the base section to form a pocket.

[c8] The assembly of claim 7, further comprising metal shims located in the pocket.

[c9] The assembly of claim 7, wherein a height of the at least three steps in the base section is less than 0.03 meters.

[c10] The assembly of claim 1, further comprising a movable permanent magnet body which is movable with respect to the second surface of permanent magnet body.

[c11] The assembly of claim 1, wherein a central step of the stepped second surface comprises a protrusion.

[c12] A magnetic imaging apparatus, comprising:

a yoke comprising a first portion, a second portion and at least one third portion connecting the first and the second portions such that an imaging volume is formed between the first and the second portions;

the permanent magnet assembly of claim 1 attached to the first yoke portion;
a second permanent magnet assembly attached to the second yoke portion,
wherein the second permanent magnet assembly comprises a second permanent
magnet body having a first surface and a stepped second surface which is adapted to
faces the imaging volume of the imaging apparatus, wherein the stepped second
surface contains at least four steps; and

wherein the apparatus does not contain a pole piece or a gradient coil between
the imaging surfaces of the permanent magnet bodies of the first and the second
magnet assemblies and the imaging volume.

[c13] A permanent magnet assembly for an imaging apparatus, comprising:

at least one layer of a soft magnetic material; and
a permanent magnet body comprising:

a cylindrical base section having a major first surface attached to the at
least one layer of a soft magnetic material and a major second surface opposite
to the major first surface of the base section; and

a hollow ring section having a major first surface and a major second
surface, wherein:

the major first surface of the hollow ring section is attached to
an outer portion of the major second surface of the base section; and

the major second surface of the hollow ring section extends at
least 0.05 meters above an adjacent portion of the major second surface
of the base section to form a pocket.

[c14] The assembly of claim 13, wherein:

wherein the first and second surfaces of the base section and the first and
second surfaces of the hollow ring section are arranged substantially perpendicular to
a direction of a magnetic field of the magnet assembly;

the base section comprises at least two layers of permanent magnet blocks;
and

at least two of the steps in the major second surface of the base section are
machined into the second surface.

[c15] The assembly of claim 14, wherein:

the permanent magnet body comprises a first surface comprising the first surface of the base portion, and a stepped second surface which is adapted to face an imaging volume of the imaging apparatus; and

the stepped second surface of the permanent magnet body comprises the second surface of the hollow ring section and a portion of the second surface of the base section that is not covered by the hollow ring section.

[c16] The assembly of claim 15, wherein:

the permanent magnet body comprises a permanent magnet RMB material, where R comprises at least one rare earth element and M comprises at least one transition metal;

the permanent magnet RMB material comprises 13-19 atomic percent R, 4-20 atomic percent B and the balance M, where R comprises 50 atomic percent or greater Pr, 0.1-10 atomic percent of at least one of Ce, Y and La, and the balance Nd, and M comprises Fe; and

the at least one layer of a soft magnetic material comprises a laminate of Fe-Si, Fe-Al, Fe-Co, Fe-Ni, Fe-Al-Si, Fe-Co-V, Fe-Cr-Ni or amorphous Fe- or Co-base alloy layers.

[c17] The assembly of claim 15, further comprising:

metal shims located in the pocket; and

a movable permanent magnet body which is movable with respect to the stepped second surface of permanent magnet body.

[c18] The assembly of claim 14, wherein inner steps of the stepped second surface of the permanent magnet body have a height less than 0.03 meters.

[c19] The assembly of claim 14, wherein a central step of the major second surface of the base section comprises a protrusion.

[c20] A magnetic imaging apparatus, comprising:

a yoke comprising a first portion, a second portion and at least one third portion connecting the first and the second portions such that an imaging volume is formed between the first and the second portions;

the permanent magnet assembly of claim 13 attached to the first yoke portion;

a second permanent magnet assembly attached to the second yoke portion, wherein the second permanent magnet assembly comprises a second permanent magnet body having a first surface and a stepped second surface which is adapted to faces the imaging volume of the imaging apparatus, wherein the stepped second surface contains at least four steps; and

wherein the system does not contain a pole piece or a gradient coil between the imaging surfaces of the permanent magnet bodies of the first and second magnet assemblies and the imaging volume.

[c21] A method of making a permanent magnet assembly, comprising:

forming at least two layers of blocks of unmagnetized material;

attaching the at least two layers of blocks to each other to form a base section of a first precursor body, the base section having a first major surface and an opposite second major surface, such that the thickness of the at least two layers of blocks is substantially perpendicular to the first and the second major surfaces;

shaping the second major surface of the base section to form at least three steps in the second major surface;

forming a hollow ring section of the first precursor body comprising a plurality of blocks of unmagnetized material;

attaching the hollow ring section to the second major surface of the base section to form the first precursor body; and

magnetizing the first precursor body to form a first permanent magnet body.

[c22] The method of claim 21, wherein:

the base section comprises a cylindrical section; and

the step of shaping the second major surface of the base section comprises machining the second major surface of the base section.

[c23] The method of claim 21, further comprising:

providing a layer of adhesive material on the second major surface of the base section; and

placing the hollow ring section on the layer of adhesive material.

[c24] The method of claim 21, wherein the step of magnetizing comprises:

providing a support comprising a first portion, a second portion and at least one third portion connecting the first and the second portions such that an imaging volume is formed between the first and the second portions;

attaching the first precursor body to the first support portion; and

magnetizing the unmagnetized material in the first precursor body to form a first permanent magnet body after the step of attaching the first precursor body.

[c25] The method of claim 24, further comprising:

attaching a second precursor body comprising a second unmagnetized material to the second support portion; and

magnetizing the second unmagnetized material to form a second permanent magnet body after the step of attaching the second precursor body.

[c26] The method of claim 25, wherein:

the step of magnetizing the first precursor body comprises placing a coil around the first precursor body; applying a pulsed magnetic field to the first precursor body to form at least one first permanent magnet body; and removing the coil from the first permanent magnet body; and

the step of magnetizing the second precursor body comprises placing a coil around the second precursor body; applying a pulsed magnetic field to the second precursor body to form at least one second permanent magnet body; and removing the coil from around the second permanent magnet body.

[c27] The method of claim 26, wherein:

the step of placing a coil around the first precursor body comprises placing a first coil around the first precursor body;

the step of placing a coil around the second precursor body comprises placing a second coil around the second precursor body;

the imaging system comprises a magnetic resonance imaging system; and

the support comprises a yoke.

[c28] The method of claim 27, wherein the first and the second permanent magnet bodies comprise an assembly of plurality of blocks having the same composition comprising an RMB alloy, where R comprises at least one rare earth element and M comprises at least one transition metal.

[c29] The method of claim 26, further comprising attaching at least one layer of a soft magnetic material between the first precursor body and the first support portion.

[c30] The method of claim 21, wherein:

the hollow ring section height is at least 0.05 meters; and

a height of the steps in the base section is less than 0.03 meters.

[c31] The method of claim 30, wherein:

the first permanent magnet body comprises a first surface and a stepped second surface which is adapted to face an imaging volume of the imaging apparatus, wherein the stepped second surface contains at least four steps; and

the hollow ring section extends at least 0.05 meters above an adjacent portion of the second surface of the base section to form a pocket.

[c32] The method of claim 31, further comprising filling the pocket with shims.

[c33] The method of claim 32, further comprising:

designing the permanent magnet body and the shim dimensions at the same time; and

forming the permanent magnet body and filling the pocket with the shims based on the design.

[c34] The method of claim 21, wherein a central step in the second major surface of the base section comprises a protrusion.

[c35] A permanent magnet assembly for an imaging apparatus comprising a permanent magnet body having a first surface and a stepped second surface which is adapted to face an imaging volume of the imaging apparatus, wherein a central step of the stepped second surface comprises a protrusion.

[c36] The assembly of claim 35, further comprising at least one layer of soft magnetic material attached to a substantially flat first surface of the permanent magnet body.

[c37] The assembly of claim 36, wherein:

the permanent magnet body comprises a permanent magnet RMB material, where R comprises at least one rare earth element and M comprises at least one transition metal;

the permanent magnet RMB material comprises 13-19 atomic percent R, 4-20 atomic percent B and the balance M, where R comprises 50 atomic percent or greater Pr, 0.1-10 atomic percent of at least one of Ce, Y and La, and the balance Nd, and M comprises Fe; and

the at least one layer of a soft magnetic material comprises a laminate of Fe-Si, Fe-Al, Fe-Co, Fe-Ni, Fe-Al-Si, Fe-Co-V, Fe-Cr-Ni or amorphous Fe- or Co-base alloy layers.

[c38] The assembly of claim 35, wherein the permanent magnet body comprises:

a cylindrical base section having a major first surface attached to the at least one layer of a soft magnetic material and a major second surface having at least three steps, wherein the second surface of the base section is opposite to the first surface of the base section; and

a hollow ring section attached to an outer portion of second surface of the base section.

[c39] The assembly of claim 38, wherein:

the first and second surfaces of the base section and the first and second surfaces of the hollow ring section are arranged substantially perpendicular to a direction of a magnetic field of the magnet assembly;

the stepped second surface of the permanent magnet body comprises the second surface of the hollow ring section and a portion of the second surface of the base section that is not covered by the ring section;

the base section comprises at least two layers of permanent magnet blocks;
and

at least two of the steps in the second surface of the base section are machined into the second surface of the base section.

[c40] The assembly of claim 39, wherein:

the second surface of the ring section extends at least 0.05 meters above an outer step on the second surface of the base section to form a pocket; and

a height of the at least three steps in the base section is less than 0.03 meters.

[c41] The assembly of claim 40, further comprising metal shims located in the pocket.

[c42] The assembly of claim 35, wherein:

the stepped second surface comprises a plurality of rings;

the central step comprises a solid central ring;

outer steps comprise a plurality of hollow rings; and

the solid central ring has a height that is greater than a height of a first hollow ring adjacent to the solid central ring, but less than a height of other plurality of hollow rings.

[c43] The assembly of claim 35, further comprising a movable permanent magnet body which is movable with respect to the second surface of permanent magnet body.

[c44] The assembly of claim 35, wherein the movable permanent magnet body is located in an opening extending from the first surface of the permanent magnet body partially through the permanent magnet body.

[c45] A magnetic imaging apparatus, comprising:

- a yoke comprising a first portion, a second portion and at least one third portion connecting the first and the second portions such that an imaging volume is formed between the first and the second portions;

- the permanent magnet assembly of claim 35 attached to the first yoke portion;

- a second permanent magnet assembly attached to the second yoke portion,

wherein the second permanent magnet assembly comprises a second permanent magnet body having a first surface and a stepped second surface which is adapted to faces the imaging volume of the imaging apparatus, wherein the stepped second surface contains at least four steps; and

- wherein the apparatus does not contain a pole piece or a gradient coil between the imaging surfaces of the permanent magnet bodies of the first and the second magnet assemblies and the imaging volume.